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Environmental efficiency in the agricultural sector of Latin America and the Caribbean 1990–2015: Are greenhouse gas emissions reducing while agricultural production is increasing?

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ABSTRACT

The paper explores the relationship between production and greenhouse gas (GHG) emissions in the agricultural sector of Latin America and the Caribbean (LAC) between 1990 and 2015. By appraising how GHG emissions have changed with respect to agricultural production (elasticity), we are able to classify countries into six decoupling states. While the decoupling elasticity provides information for assessing the evolution within countries, we introduce a performance ratio for country comparison by calculating GHG emissions over agricultural production for 2015 and using the global distribution as benchmark. The information from both measurements serves to identify various country and sub regional situations. The findings illustrate that countries with performance ratios in the top 25% and under the best-case elasticity scenario (of *strong decoupling)* are not necessarily the same as the ones usually identified under factor productivity analyses, suggesting that environment-specific policy incentives and tools play a key role in enhancing sustainable agricultural production. Another major finding is that very few countries in the region (and worldwide) are able to offset agriculture emissions with land use-related carbon sequestration practices. Lastly, the evidence on small Caribbean island-states reporting the worst-case elasticity scenario (of *strong negative decoupling)* and performance ratios close to the world median, further supports the need for development plans related to climate change mitigation and adaptation in this sub region.

1. Introduction

Decoupling refers to breaking the link between "environmental bads" and "economic goods" (OECD, 2002) or delinking economic development from environmental deterioration (UNEP, 2011). This notion is particularly relevant in the agricultural sector that currently faces a dual challenge of reducing greenhouse gas (GHG) emissions and expanding production to fulfill an increasing food, feed and fiber demand in a context of increasing climate variability (FAO, 2016a). In this respect, the literature indicates that global agriculture has been getting more efficient in terms of GHG emissions per production unit with vast regional differences (Bennetzen et al., 2016a). In a 40-year trend analysis by Bennetzen et al. (2016b), Central and South America achieved a reduction of 57% of GHG emissions per crop unit and 61% per livestock unit. However, in absolute terms the ratio of GHG agricultural emissions per agricultural production unit was on average 10 times higher than the European region, which is recognized as one of the top performers in this area.

While previous studies indicate that the decoupling evolution of agricultural production from GHG emissions in the Latin America and the Caribbean (LAC) is aligned to global trends (Bennetzen et al., 2016a,b) equivalent assessments which highlight the main differences across the agricultural sectors of LAC countries and sub regions[1] are lacking. This gap is relevant because agricultural, forestry and other land use change (AFOLU) GHG emissions in LAC account for 42% of the region's overall GHG emissions while the global average is 18% (ECLAC, 2018). As argued by Clarke et al. (2016) climate policy in LAC countries may need to focus more heavily on land and agriculture than in other world regions.

The decoupling of GHG emissions from agricultural production is also pertinent because, the region is on average a net food exporter. Flachsbarth et al. (2015), based on World Trade Organization data, indicate that between 1980 and 2010, LAC's agricultural market share almost doubled from 9.5% to 18.1%. Recent data show that about a

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[1] See Appendix 1 for an overview of countries within each sub region; Caribbean, Central America and South America.

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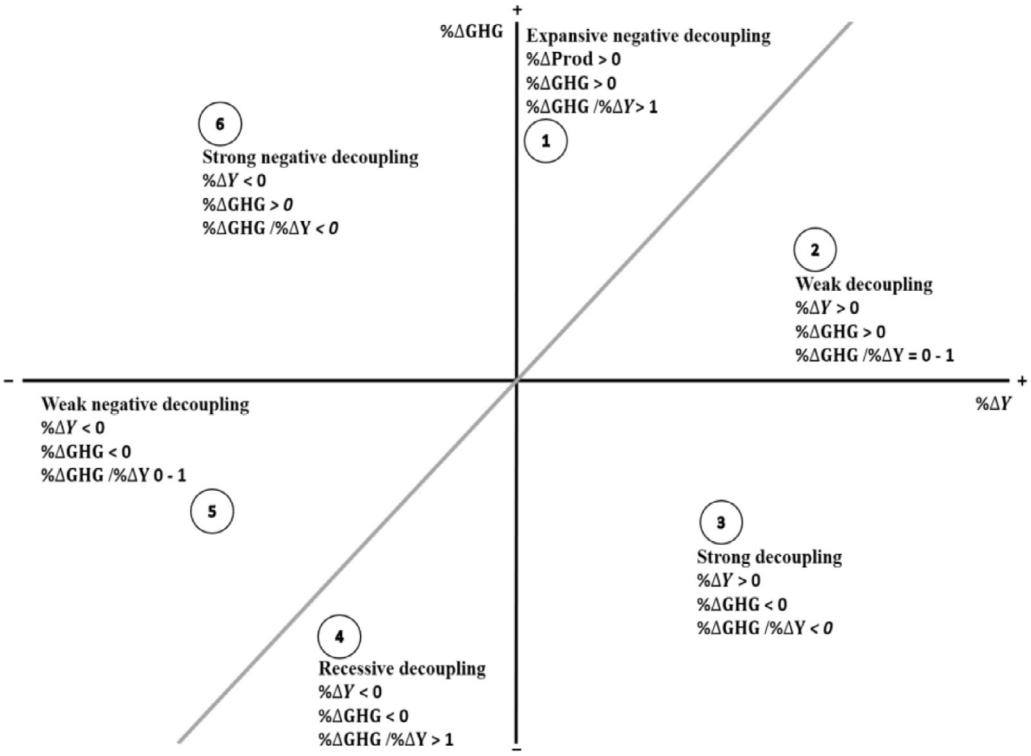

Fig. 1. Six Decoupling Elasticity States of Agricultural Production (Y) from GHG emissions. Source: Adapted from Tapio (2005) and Ren and Hu (2012).

quarter of the region's total exports belongs to the agricultural sector and this share is the largest among all other regions in world trade (Lopez et al., 2017). This strong dependence on the agricultural sector further justifies the urgency to adopt sustainable production practices (beyond GHG reductions) so that the sector may continue contributing to regional economic growth and long-term development.

Therefore, the aim of this paper is twofold. First, we explore the decoupling elasticity states of agricultural production from agricultural forestry and land use change GHG emissions in LAC countries for the largest available timeframe, which is from 1990 to 2015. The hypothesis is that regional averages hide very different country-specific evolutions. Second, unlike previous regional studies, agricultural GHG emissions (A) as well as AFOLU GHG emissions are examined. The distinction is relevant because the expansion of the agricultural frontier is identified as the main reason for forest loss under unregulated contexts (FAO, 2016b).

In summary, by leveraging self-reported national data based on internationally agreed methodological guidelines, this study seeks to fill in a gap in the literature, i.e. assessing how agricultural and AFOLU GHG emissions have behaved with respect to agricultural production over a 26 year period. To unravel national and sub regional differences, two measurements are used simultaneously to identify which LAC countries are effectively decoupling (or not) their GHG emissions from agricultural production and to what extent (i.e. emitted tons per production unit). Ultimately, the findings from this study are expected to enhance both technical and political commitment to the wider and faster adoption of sustainable environmental practices in the agricultural sector in Latin America and the Caribbean and to fuel the public policy debates on how to tackle food insecurity and climate change challenges.

2. Methods and data

There are three widely used quantitative decoupling estimators in the literature (Conte, 2016). The OECD (2002) decoupling degrees, Tapio's (2005) decoupling elasticities and Luo et al. (2017) decoupling indicator. In this paper, we select Tapio's (2005) approach for two main reasons. First, the decoupling elasticities offer the possibility to study up to eight different categories of decoupling with more specificity on the analysis of both "environmental bads" and "economic goods". Second, the approach, initially conceived for the transport sector, has been successfully applied in a variety of economic sectors, including electric energy (Zhang and Wang, 2013; Wang and Ynag, 2015); non-ferrous metal industry (Ren and Hu, 2012), energy consumption, (Zhao et al., 2006), fresh water consumption and waste emissions (UNEP, 2011) and the agricultural sector (Luo et al. 2017).

The decoupling elasticities in LAC agricultural sector for the 1990–2015 period are calculated through the following three equations based on Tapio (2005):

$$\%\Delta_{GHG1990-2015i} = (GHG_{2015i} - GHG_{1990i})/GHG_{1990i} \quad (1)$$

$$\%\Delta_{Y1990-2015i} = (Y_{2015i} - Y_{1990i})/Y_{1990i} \quad (2)$$

$$e_{1990-2015i} = \frac{\%\Delta_{GHG1990-2015i}}{\%\Delta_{Y1990-2015i}} \quad (3)$$

where

$\%\Delta_{GHG1990-2015i}$ in Eq. (1) denotes the percentage change of the GHG emissions between 1990 and 2015 for LAC country or sub region *i*. GHG emissions are measured in terms of CO_2 equivalent tons.

$\%\Delta_{Y1990-2015i}$in Eq. (2) represents the percentage change of agricultural production between 1990 and 2015 for LAC country or sub region *i*. Agricultural production (Y) is measured in international dollars based on constant price series.

$e_{1990-2015i}$ in Eq. (3) stands for the decoupling elasticity state of LAC country or sub region *i* between 1990 and 2015.

Fig. 1 presents six of the eight different decoupling elasticity states as defined by Tapio (2005). The reason for omitting two states that refer to elasticities close to one (0.8 to 1.2) was mainly to facilitate the discussion of results. Ren and Hu (2012) and Vehmas et al. (2007) have already implemented the same approach that identifies the

corresponding six decoupling states, presented in this paper.

Elasticities falling into the upper right-hand side quadrant, represent states where both agricultural production and GHG emissions during the 1990 and 2015 period increased, but at different rates:

1. *expansive negative decoupling* refers to the situations where GHG emissions grew faster than agricultural production.
2. *weak decoupling* refers to the cases where agricultural production increased faster than GHG emissions in the sector;

The lower right-hand side quadrant represents the best possible scenario associated to sustainable intensification:

3. *strong decoupling* refers to the situation where agricultural production expands while GHG emissions of the sector decrease

The lower left-hand side quadrant introduces two elasticity states where both variables decreased during the 1990–2015 period:

4. *recessive decoupling* is when GHG emissions decreased faster than agricultural production.
5. *weak negative decoupling* state is the case where agricultural production decreased faster than GHG emissions

The worst-case scenario is represented in the upper left-hand side quadrant:

6. *strong negative decoupling* showcases an expansion of GHG emissions and a reduction of agricultural production

To calculate decoupling elasticity states, we use the FAOSTAT database (FAO, 2018) that contains comparable time series indicators among countries and sub regions for both GHG sector-related emissions and agricultural production. For the analysis of GHG emissions in Eq. (1), FAOSTAT presents decomposed information of agricultural (A) GHG emissions as well as forestry and other land use related (FOLU) GHG emissions. These Agricultural and FOLU GHG emissions are estimated by national authorities and later reported to FAO following an internationally adopted methodological approach which allows for their merging under the term of AFOLU GHG emissions. The AFOLU GHG data are based on the international climate policy agreements and technical guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) in accordance with the United Nations Framework Convention on Climate Change (FAO, 2015). One advantage of following IPCC Guidelines to build GHG inventories for any sector is that these are subject to frequent efficiency and quality controls (ibid). In the case of AFOLU measurements, specific improvements have been achieved through:

a) the removal of the somewhat arbitrary distinction between categories in the previous versions of the IPCC guidelines, and b) consistency in the treatment of gases in the agriculture and land use, land-use change, and forestry (LULUCF) sectors; thus enabling a more consistent treatment of land conversions (FAO, 2015).

The AFOLU anthropogenic GHG emissions and removals include all emissions and removals occurring on 'managed land' and that are associated with the use of land, including crop production and animal husbandry. Managed land is land where human interventions have been applied to perform economic, ecological or social functions (IPCC, 2006; FAO, 2015). The components of GHG emissions and removals deriving from AFOLU are summarized in Table 1. To allow for the consolidation of these various components, they are used in terms of CO_2 equivalent tons of GHG emissions.

For Eq. (2), *Gross Value of Agricultural Production* measured in constant price series using international dollars is selected as main indicator for aggregated agricultural production. In FAOSTAT, this indicator is built by multiplying gross production in physical terms by output prices at farm gate, considering only primary agricultural production. The constant price series for 2004–2006 displays the real evolution of the quantity or volume of products, thus controlling for inflation, while the usage of "international commodity prices"[2] controls for any exchange rate bias. In other words, the unit in international dollars allows capturing the physical expansion/contraction of agricultural production and not its market or economic value. One main advantage of this value-based production variable (instead of separate animal and plant-based production indices) is that it allows integrating agricultural production and making it comparable to agricultural emissions that intrinsically combine livestock and crop-related GHG emissions. However, one disadvantage of this indicator is that it excludes any gross production value associated with the forestry sector. Instead of making assumptions to expand the denominator of the elasticity (Eq. (3)), we evaluate how primary agricultural production stands against agricultural emissions only and AFOLU emissions, the latter represents a stricter evaluation scenario (assuming the difference between FOLU emissions and removals is positive). This is pertinent because the literature has often made a connection between agricultural expansion and deforestation (Lamb et al., 2016; Graesser et al. 2015).

Besides calculating the decoupling elasticities for each country and sub region in LAC between 1990 and 2015, two complementary performance ratios are introduced using 2015 data:

)i. Agricultural GHG emissions/Agricultural Production (Y)
)ii. AFOLU GHG emissions/Agricultural Production (Y)

While the elasticities give information on the evolution over the 1990–2015 period, the ratio provides a comparable overview of performance in the most recent year available in FAOSTAT. Two ratios are used in order to highlight the differential effects of measuring only agricultural emissions or AFOLU emissions against agricultural production. These ratios are relevant, because it is not the same to have two countries under the same state of decoupling, but one of them emitting twice GHG for the same volume of agricultural production. The global distribution of performance ratios will be used to identify thresholds achieved by the top and bottom 25% of countries, giving insights on relative performance at the most recent available year. In most cases, the ratios will be positive and smaller numbers will reflect higher environmental performance. It should however be noted that a negative ratio can be reported when AFOLU GHG removals are larger than agricultural emissions. In such cases the country is capturing carbon while producing, thus indicating an even better performance in environmental terms due to carbon sequestration practices in their land management strategies.

3. Results and discussion

3.1. Decoupling elasticities of agricultural and AFOLU emissions from agricultural production 1990–2015

Figs. 2 and 3 present decoupling elasticities states of LAC countries, sub regions and the world averages using agricultural emissions and AFOLU emissions/removals, respectively. The differences between both elasticities states reflect the extent to which land management practices contribute to GHG removals or emissions, providing insights on the

[2] International prices result from the iterative comparison, through mathematical methods, of the production value of all commodities in all countries, obtained from the producer prices of each commodity/country, with the corresponding value of production in the United States obtained in a similar manner. With the operation, both special exchange rates to US dollars for each country and thereby special commodity prices for each commodity are obtained: The so-called "International dollars". (FAOSTAT, 2018)

Table 1
Overview of AFOLU GHG emission components.

A (Agricultural emissions)	FOLU (Forest and Land Use emissions)
• CO_2 from cultivated organic soils; • non-CO_2 emissions from fire on all managed land; • CH_4 emissions from rice cultivation; • N_2O emissions from all managed soils; • CO_2 emissions associated with liming and urea application to managed soils; • CH_4 emissions from livestock enteric fermentation; • CH_4 and N_2O emissions from manure management systems.	• CO_2 emissions and removals resulting from carbon stock changes in biomass, dead organic matter (DOM), soil organic matter (SOM) of organic and mineral soils, and harvested woody products (HWP) for all managed lands;

Note: See Appendix 2 for a description of definitions used in AFOLU components.
Source: FAO (2015).

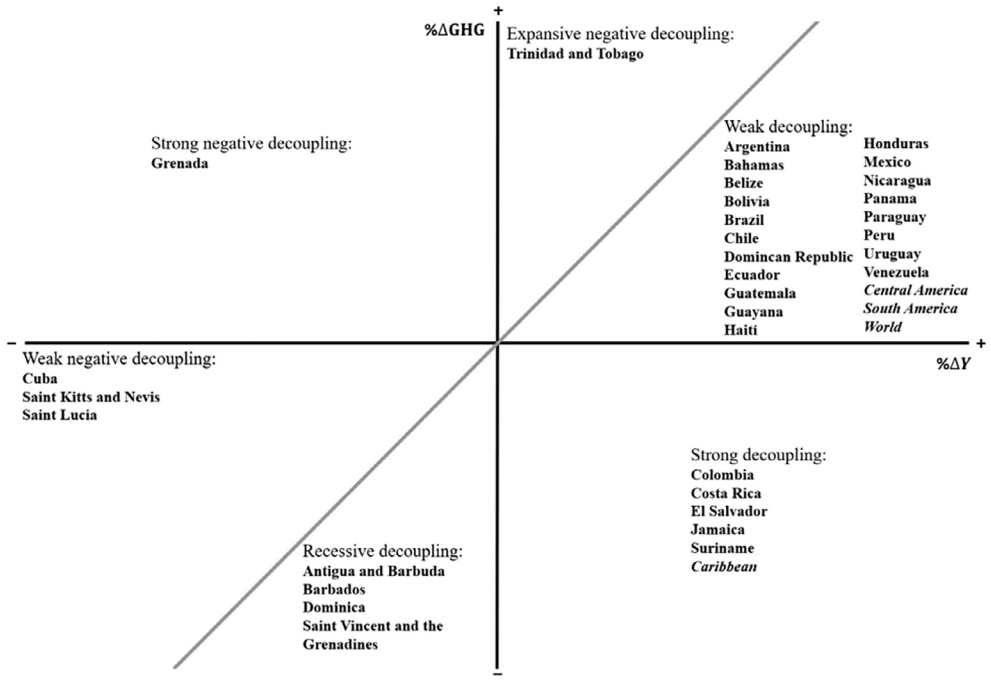

Fig. 2. Decoupling Elasticity States of agricultural production in LAC countries, sub regions and the world from agricultural emissions.

relation between agricultural production evolution and FOLU trends.

At a first glance, most LAC countries and sub regions are in states of *weak* or *strong decoupling* independently of the used GHG emissions. However, there are various aspects to consider. The Caribbean, a sub region not included in previous global level analyses, reports a state of *strong decoupling* when considering only agricultural emissions, but when forestry and other land use emissions are included in the measurement, its state becomes one of *expansive negative decoupling*. The latter would suggest that there are, on average, limited capacities for carbon sequestration in land use management in this sub region. However, the Caribbean average may be capturing the trend of larger countries, particularly in terms of agricultural production, because most of the small islands report a state of *recessive decoupling* for the case of agricultural emissions only and one of *strong negative decoupling* for the case of AFOLU.

The elasticity states for Central America and South America confirm conclusions of previous decoupling studies based on agricultural emissions (Bennetzen et al., 2016b), where these sub regions, displayed a *weak decoupling*. However, when adding the forestry and other land use emissions into the measurement, the Central and South America move to a state of *strong decoupling*. The latter may be aligned to policies aimed at halting deforestation, partly associated to the containment of cattle area expansion, particularly in Brazil (Oliveira Silva et al., 2016; Lapola et al., 2014).

When moving to the country level analysis and only considering agricultural emissions, we find that only five countries achieve a state of *strong decoupling*: Colombia, Costa Rica, El Salvador, Jamaica and Suriname. If forestry and other land use emissions/removal are included in the elasticity measurement, the list grows to include Belize, Brazil, Chile, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Trinidad and Tobago and Venezuela. Twelve of the latter 13 countries – the exception being Trinidad and Tobago - had achieved a state of *weak decoupling* when only agricultural emissions were considered. This means that reductions of FOLU GHG emissions (or rather CO_2 removals) over the 26 year period are an important component, while in the former group of five countries, both agricultural practices and land management are jointly contributing to reducing GHG emissions in the sector, while increasing agricultural production.

In the cases of countries remaining in the same state of *weak decoupling* (such as Argentina, Bolivia, Dominican Republic, Paraguay and Peru) the addition of the FOLU emissions into the elasticity measurement was not enough to alter their trends. In the cases of Bahamas and Uruguay, where a move from a *weak decoupling* to an *expansive negative decoupling* state is registered, it can be said that FOLU emissions increased (as in Bahamas) or FOLU removals decreased (as in Uruguay) over the 26 year period of study.

In terms of the undesired scenario of *strong negative decoupling*

Fig. 3. Decoupling Elasticity States of agricultural production in LAC countries, sub regions and the world from AFOLU emissions Note: See Appendix 3 for the detail of the measurement of decoupling elasticity states.

(upper left-hand side of diagram), we see that while only Grenada is in this state when considering agricultural emissions, the group expands to include Antigua and Barbuda, Cuba, Dominica, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines when AFOLU emissions are considered. These findings suggest that these countries have had negative agricultural production growth as well as reduced capacity for maintaining or expanding carbon sequestration over this 26-year period. It is important to highlight that this group is mainly composed of small island-states, which are net agricultural importers and usually highly vulnerable to climatic events.

3.2. Performance ratios: agricultural and AFOLU emissions over agricultural production in 2015

So far, we have only discussed evolution of agricultural production and of the related sector emissions between 1990 and 2015, as captured by decoupling elasticity states under agricultural and AFOLU emissions. The introduction of a performance ratio using both agricultural as well as AFOLU emissions, will enable us to assess how countries are performing in relation to each other in the last available year (2015) and not only in terms of their own evolution in the last 26 years.

In general (and as expected), when compared to agricultural emissions, the consideration of AFOLU emissions increases the number of emitted GHG tons per 1000 USD of agricultural production. As already mentioned, this entails a stricter evaluation of agricultural production by adding more sources of GHG emissions. This situation is true for 26 countries[3] that report higher AFOLU than agricultural ratios, as portrayed in Fig. 4. The larger the difference between the two ratios, the larger the weight of deforestation, soil degradation and other carbon releasing activities associated to land use change in 2015. For example, the performance ratio of Bahamas moves from 1 GHG ton per 1000 USD of agricultural production to 13 emitted GHG tons per 1000 USD of agricultural production.

There are six countries with FOLU sectors removing or capturing GHG in 2015 rather than emitting. In such cases, the AFOLU ratio will be smaller than the one considering only agricultural emissions (as in the case of Uruguay that moves from 6 to 3 GHG emitted tons per 1000 USD of agricultural production). In the countries where the captures of the FOLU sector surpass the emissions of agriculture, the ratio considering AFOLU emissions will then be negative (Chile, Costa Rica, Trinidad and Tobago, Cuba, Dominican Republic). In other words, a negative AFOLU ratio implies CO_2 removals rather than emissions per 1000 USD of agricultural production in 2015.

Table 2 introduces the global distribution of performance ratios of agricultural and AFOLU emissions/removals over agricultural production considering up to 188 countries for which FAOSTAT has updated data. By observing how performance ratios are distributed at a global level by percentiles, it is possible to identify which LAC countries are below or above the median of this distribution and which ones belong to the bottom or top 25%. In 2015, the global top 25% of countries achieved a performance ratio equal or below 1.3 emitted tons per 1000 USD of agricultural production when considering only agricultural

[3] Grenada is not considered because there is no data of FOLU emissions reason why both ratios are the same

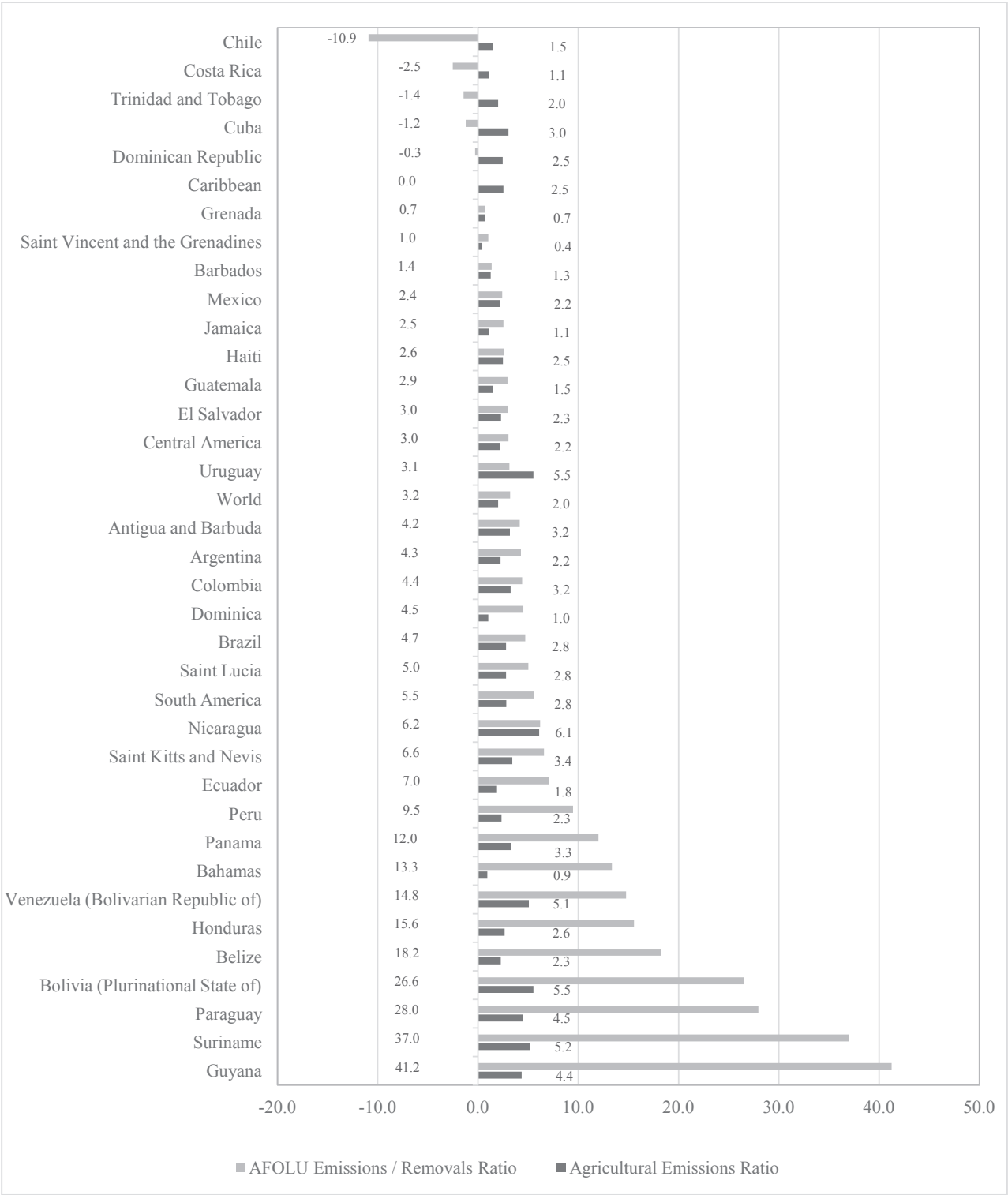

Fig. 4. Performance ratios Agricultural and AFOLU Emissions/Removals of GHG per 1000 USD of agricultural production in 2015 Note: AFOLU performance ratios presented to the left and Agricultural performance ratios to the right.

emissions. In LAC only Saint Vincent and the Grenadines, Grenada, Bahamas, Dominica, Costa Rica, Jamaica and Barbados belong to this segment. At the other end of the spectrum (the bottom 25%) we find countries reporting ratios equal or above 3.9 emitted tons per 1000 USD of agricultural production. In LAC this included Nicaragua, Bolivia, Uruguay, Suriname, Venezuela, Paraguay and Guyana.

When considering the performance ratio incorporating AFOLU emissions, in 2015 the top 25% achieved a ratio equal or below 0.9 emitted GHG ton per 1000 USD of agricultural production. That segment included five countries reporting negative ratios[4]: Chile, Costa Rica, Trinidad and Tobago, Cuba and Dominican Republic. On the other hand, the bottom 25% achieved a ratio equal or above 8.2 emitted tons per 1000 USD of agricultural production. In LAC this included the

[4] Only 25 countries worldwide reported negative AFOLU ratios in 2015.

Table 2
Global distribution of Performance ratio (Agricultural emissions and AFOLU emissions/removals measured in GHG tons per 1000 international dollars of agricultural production) by percentile in 2015.

Percentile	$ratio_{ag} = \frac{GHG_{ag}}{Y} * 1000$	$ratio_{afolu} = \frac{GHG_{afolu}}{Y} * 1000$
5%	0.7	−2.6
10%	0.9	−0.5
15%	1.1	0.2
20%	1.2	0.6
25%	1.3	0.9
30%	1.5	1.2
35%	1.7	1.4
40%	1.9	2.0
45%	2.1	2.3
50%	2.3	2.9
55%	2.5	3.2
60%	2.8	4.1
65%	3.1	4.5
70%	3.4	6.3
75%	3.9	8.2
80%	4.7	9.6
85%	5.7	14.7
90%	6.6	21.1
95%	10.9	34.8

Note: Countries achieving smaller/negative ratios are the ones reporting higher relative performance in 2015.

following countries: Peru, Panama, Bahamas, Venezuela, Honduras, Belize, Bolivia, Paraguay, Suriname and Guyana.

3.3. Discussion of combined indicators related to decoupling elasticity states and performance ratio in LAC

Table 3 summarizes and combines information on decoupling elasticity states between 1990 and 2015 and performance ratios in 2015. This allows identifying various country situations in the region in terms of environmental efficiency. In other words, the table yields information on how countries have evolved in a 26-year framework (six different rows for each decoupling elasticity state) and how they compare to each other in the most recent year available both in terms of agricultural emissions (left-hand side columns of the table) and AFOLU emissions (right-hand side columns of the table). Countries in a state of *strong decoupling* between 1990 and 2015 and performance ratios in 2015 at the top 25% of the global distributions are very few: Jamaica and Costa Rica for the case of agricultural emissions and Chile, Costa Rica and Trinidad and Tobago for the case of AFOLU emissions.

The case of Costa Rica is particularly relevant because the country is in a consolidated state of *strong decoupling* with a negative performance ratio for the case of AFOLU and an agricultural emissions ratio in the top 25% of the global distribution. This indicates that over the 26-year period GHG emissions were reduced both in their agricultural as well in their land use practices while increasing agricultural production. Interestingly, the country has not only reduced livestock percentage in overall agricultural production between 1990 and 2015 (FAO, 2018) but has been openly promoting environmentally friendly practices in its agricultural and forestry sectors as well as in other sectors of its economy (MINAE, 2018). Karousakis (2007) explains that deforestation in Costa Rica was driven by *policies (particularly tariff and non-tariff barriers to international trade) including cheap credit for cattle, land titling laws that rewarded deforestation, taxes to "unproductive" lands and rapid expansion of the road system*. The removal of these policies and the promulgation of new national laws such as *Forest Law No. 7575, the Public Services and Regulatory Authority Law, the General Law of the Environment, the Soil Conservation Law and the Biodiversity Law* strengthened reforestation programs, making these accessible to small landowners within rural areas (ibid). The latter suggests that altering production mixes but particularly adopting sustainable land management and conservation practices are key instruments to achieve environmentally efficient and sustainable agricultural production (Burney

Table 3
Combination of Decoupling Elasticities States and Performance Ratio in LAC - Summary.

Decoupling Elasticities States 1990–2015	$ratio_{ag} = \frac{GHG_{ag}}{Y} * 1000$				$ratio_{afolu} = \frac{GHG_{afolu}}{Y} * 1000$			
	Bottom 25%	Below 50%	Above 50%	Top 25%	Bottom 25%	Below 50%	Above 50%	Top 25%
Expansive negative decoupling (1)			Trinidad and Tobago		Bahamas	Uruguay		
Weak decoupling (2)	Nicaragua Bolivia Uruguay Venezuela Paraguay Guyana	Belize Panama Brazil Honduras Haiti Dominican Republic Peru	Argentina Mexico Ecuador Guatemala Chile	Bahamas	Peru Bolivia Paraguay Guyana	Argentina	Haiti	Dominican Republic
Strong decoupling (3)	Suriname	El Salvador Colombia		Jamaica Costa Rica	Belize Honduras Panama Suriname Venezuela	Ecuador Nicaragua Brazil Colombia El Salvador Guatemala	Jamaica Mexico	Chile Costa Rica Trinidad and Tobago
Recessive decoupling (4)		Antigua and Barbuda		Barbados Dominica Saint Vincent and the Grenadines			Barbados	
Weak Negative decoupling (5)		Cuba Saint Lucia Saint Kitts and Nevis						
Strong negative decoupling (6)				Grenada		Saint Kitts and Nevis Saint Lucia Dominica Antigua and Barbuda	Saint Vincent and the Grenadines	Cuba

et al., 2010; Tilman et al., 2011).

It is also relevant to highlight the situation of Cuba that reports decoupling elasticity states that display a negative trend in agricultural production between 1990 and 2015. The state of *weak negative decoupling* indicates that Cuba has experienced a contraction of agricultural emissions, which has not kept pace with the faster contraction of agricultural production. On the other hand, the state of *strong negative decoupling* indicates that AFOLU removals have decreased over the 26-year period, but not enough to imply that the country is unable to produce while still capturing carbon as reported in 2015 AFOLU performance ratio. These findings suggest that market incentives should be re-visited to stimulate production following previous patterns of AFOLU GHG removals in the sector.

As already discussed, most of the small Caribbean island-states fell in elasticity states of *recessive decoupling* or *weak negative decoupling* when only considering agricultural emissions. Their situation worsens when introducing AFOLU emissions because the majority end up in a state of *strong negative decoupling,* except for Barbados that maintained the same elasticity state. While most of them are reporting performance ratios for 2015 close to the world median for the case of AFOLU, the overall trend is extremely worrying considering that most of these are food import dependent countries. Such countries leaning towards trends of agricultural production contraction require stricter control over the evolution of AFOLU GHG emissions, particularly those related to land use change.

The majority of countries from South America and Central America are in a state of *weak decoupling* or *strong decoupling* whether considering agricultural or AFOLU emissions with performance ratios in 2015 that are mostly below the world median. Only Jamaica and Mexico are reporting performance ratios above world median in a state of *strong decoupling* when considering AFOLU emissions. For all countries under *strong decoupling* states (and particularly for those reporting performance ratios that are at the bottom 25% of the world distribution), it is essential to boost agricultural production while maintaining their reduction trend on GHG emissions. Whereas for countries under *weak decoupling*, the focus on reducing GHG emissions is crucial. In these cases the environmental policy literature often refers to sustainable intensification (SI) as a package of measures to tackle both challenges (Godfray and Garnett, 2014; Campbell et al., 2014; Garnett et al., 2013). SI refers to *increasing food production from existing farmland in ways that have lower environmental impact and which do not undermine our capacity to continue producing* (Campbell et al., 2014). Interestingly, authors like Godfray and Garnett (2014) emphasize that SI may entail different practices from diverse disciplines that need to be adopted depending on specific agro-environmental contexts. In the same line, Robertson and Swinton (2005), call for a reconfiguration in the management of agricultural production so that outputs in both physical and environmental terms are considered. The latter requires that countries re-position the strategic value of agricultural research and extension services while incorporating the notion of environmental systems where trade-off are always present and alternatives need to consider social, economic and environmental consequences.

It should be noted that these are general recommendations, as we cannot make causal inferences with the data examined in this paper. We should bear in mind that the analysis uses two points in time to assess overall evolution; therefore, any radical shifts in the variables are not considered. As a result, a more in-depth and country-based examination is required to identify the determinants for the observed findings. This examination may include other elements not accounted for in this study such as: production mix (Clark et al., 2017), farmland distribution and size (Herrero et al., 2017; Lowder et al., 2015), land management strategies (whether based on land sparing or land sharing practices) (Phalan et al., 2011), bio-diversification, water harvesting (Altieri and Nicholls, 2017), etc. The combination of these elements is more likely to provide an enhanced picture of overall environmental efficiency and sustainability in agricultural sectors.

Despite this limitation, the main advantage of these internationally comparable data reported by countries using IPCC guidelines and validated by FAO is that it is the best and most recent publicly available data to evaluate agricultural and GHG emission trends. These calculations are the ones used by countries to monitor their commitment and progress to combat climate change and therefore provide a policy-relevant assessment to push for further environmental efficiency in the agricultural sectors of LAC countries and sub regions. Since this exercise was lacking in the literature, it may serve as a kick-off to more in-depth discussions and analyses.

4. Conclusions

The findings reveal that very few countries in LAC are in a process of effectively decoupling agricultural and AFOLU emissions from agricultural production. In addition, LAC countries under favorable decoupling trends and performance ratios of GHG emissions over agricultural production are not directly equivalent to top performing countries as reported under standard agricultural factor productivity indices in the region (Lopez et al., 2017; IDB, 2016). In such literature, countries with the largest land endowments (more than 10 ha per agricultural worker) usually obtain the highest-ranking positions, such as Brazil, Peru or Argentina. This has strong implications for both agricultural and environmental-agendas, as it is evident that GHG emissions are not reducing as fast as required in the agricultural sector, and the regional average is hiding strong performance variations. In this respect, a major finding is that most of the small island states in the Caribbean reported a *strong negative decoupling* state, which supports the current international development agenda for climate change adaptation and mitigation in this sub region.

In order to produce in a more sustainable manner and meet both climate change and food insecurity related obstacles, it is necessary to undertake an in-depth analysis of environmental-specific policy incentives and private sector agricultural developments. While in this paper, some recommendations emerge for specific country situations, it is necessary to go into details to incorporate other environmental dimensions besides GHG reductions.

In countries under *strong decoupling* states and top 25% performance ratios, it is relevant to identify which and how best practices were identified and adopted in terms of public policy packages and private sector stimuli. The analysis can be extended to include the type of production systems in place and the capacity or willingness of growers to embrace new techniques and practices. The latter are valuable lessons for countries under *weak decoupling* and *expansive negative decoupling* states aiming to achieve sustainable intensification objectives.

Overall, the revision of decoupling elasticities and performance ratios contribute towards an enhanced assessment of environmental efficiency in LAC's primary agricultural sector. While on average LAC countries are under a *weak decoupling* state, they can do more to accelerate decoupling of environmental "bads" from agricultural "goods". This calls for a renewed vision and public policy stimuli and regulations on the integrated management of agricultural areas and natural resources in LAC that allows moving towards a wider framework for promoting sustainable agricultural production.

Appendix 1. Sub regional composition for Latin American and Caribbean countries in FAOSTAT.

Caribbean	Central America	South America
Anguila– *	Belize	ArgentinaBolivia
Antigua and Barbuda	Costa Rica	(Plurinational State of)
Aruba–*	El Salvador	Brazil
Bahamas	Honduras	Chile
Barbados	Mexico	Colombia
British Virgin Islands– *	Nicaragua	EcuadorFalkland Islands (Malvinas)
Cayman Islands– *	Panama	– *
Curaçao– *		French Guiana– Data not available
Dominica		Guyana
Dominican Republic		Paraguay
Grenada		Peru
Guadeloupe–*		Suriname
Haiti		UruguayVenezuela
Jamaica		(Bolivarian Republic of)
Martinique–*		
Montserrat– *Netherlands Antilles		
(former) –*		
Puerto Rico–*		
Saint Kitts and Nevis		
Saint LuciaSint Maarten		
(Dutch Part) – *Saint-Martin		
(French Part) – *		
Saint Vincent and the Grenadines		
Trinidad and Tobago		
Turks and Caicos Islands –*		
United States Virgin Islands–*		

Note: * Agricultural/AFOLU emissions not available.

Appendix 2. AFOLU definitions of sources and sinks (FAO, 2015)

Agricultural practices leading to GHG emissions include the following categories

- *Enteric fermentation.* This is the fermentation process that produces methane as a by-product of the normal livestock digestive process, in which microbes resident in the animal's digestive system ferment the feed consumed by the animal.
- *Manure management.* Livestock manure is primarily composed of organic material and water. Under anaerobic conditions, the organic material is decomposed by anaerobic bacteria. The end products of anaerobic decomposition are methane, carbon dioxide, and stabilized organic material. The methane production potential of manure depends on the manure's specific composition, which in turn depends on the composition and digestibility of the animal diet.
- *Biomass burning.* It includes only living biomass. Although, the fuel components other than live biomass are often very significant, especially in peatlands (i.e. DOM).
- *Managed soils.* This category includes all agricultural soils. This category includes direct and indirect nitrous oxide emissions that are usually estimated from data on nitrogen supplied to soils, including nitrogen fertiliser usage or sales, crops residue management, organic amendments, cultivation of organic soils (i.e. drainage of peatlands in agricultural land) and land-use conversions that enhance mineralisation of nitrogen in soil organic matter.
- *Liming* is used to reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests. Adding carbonates to soils in the form of lime (e.g., calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate ($2HCO_3$), which evolves into CO_2 and water (H_2O). These are methods for soil fertilization. Adding urea to soils during fertilisation leads to a loss of the CO_2 that was fixed in the industrial production process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4^+), a hydroxyl ion (OH–), and bicarbonate (HCO_3^-), in the presence of water and urease enzymes. Similar to the soil reaction following addition of lime, the bicarbonate that is formed evolves into CO_2 and water. This source category is included because the CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use Sector.
- *Rice cultivation.* This category refers to the anaerobic decomposition of organic material in flooded rice fields that produces methane, which escapes to the atmosphere primarily through air-bubbles and by being transported through the rice plants. The amount emitted is a function of the rice species, the number and duration of harvests, the soil type and temperature, the irrigation method, and fertilizer use.

Land use practices related to FOLU emissions

Each land use is subdivided into land remaining in the same category (e.g. Forest land Remaining forest land) and land converted from one category to another (e.g. Forest land converted to cropland). Countries may choose to further stratify land in each category by climatic or other ecological regions, depending on the choice of the method and its requirements. Greenhouse gas emissions and CO_2 removals determined for each specific land use include CO_2 (as carbon stock changes) from biomass, dead organic matter, soils and HWP, if any, as well as non-CO_2 emissions from burning.

Land use comprises the following categories

- *Forestland.* This category includes all land with woody vegetation consistent with the thresholds used to define forestland in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but that in situ could potentially reach, the threshold values used by a country to define the forest land category.
- *Cropland.* This category includes cropped land, including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the forest land category.
- *Grassland.* This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation, such as herbs and brushes that fall below the threshold values used in the forestland category. The category also includes all grassland, from wild lands to recreational areas as well as agricultural and silvo-pastoral systems, consistent with national definitions.
- *Wetlands.* This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g. peatlands), and that do not fall within the forestland, cropland, grassland or settlements categories. It includes reservoirs as a managed sub-division, and natural rivers and lakes as unmanaged subdivisions.
- *Settlements.* This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. The elements falling within this category should be consistent with national definitions.
- *Other land.* This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It enables the total of identified land areas to match the national area, where data are available. If data are available, countries are encouraged to classify unmanaged lands by the above land-use categories (e.g. Unmanaged forest land, unmanaged grassland, and unmanaged wetlands).

Appendix 3. Measurement of decoupling elasticity states in LAC countries 1990–2015.

Country	$\frac{Y_{2015i} - Y_{1990i}}{Y_{1990i}}$	$\frac{GHG_{2015i} - GHG_{1990i}}{GHG_{1990i}}_{ag}$	$\frac{GHG_{2015i} - GHG_{1990i}}{GHG_{1990i}}_{afolu}$
Antigua and Barbuda	−0.186	0.522	−0.418
Argentina	1016	0.189	0.032
Bahamas	0.777	1351	0.359
Barbados	−0.235	−0.246	−0.436
Belize	0.906	−0.42	0.824
Bolivia (Plurinational State of)	1536	0.168	0.708
Brazil	1629	−0.367	0.479
Chile	0.904	−28,270	0.376
Colombia	0.608	−0.656	−0.018
Costa Rica	0.933	−1743	−0.225
Cuba	−0.302	0.818	−0.218
Dominica	−0.241	74,045	−0.246
Dominican Republic	0.979	0.805	0.453
Ecuador	1012	−0.142	0.091
El Salvador	0.293	−0.108	−0.092
Grenada	−0.052	0.036	0.035
Guatemala	1901	−0.179	0.873
Guyana	1619	0.719	0.786
Haiti	0.708	0.43	0.454
Honduras	0.85	−0.254	0.215
Jamaica	0.145	−0.189	−0.365
Mexico	0.772	−0.032	0.091
Nicaragua	1473	−0.714	0.614
Panama	0.205	−0.004	0.11
Paraguay	1283	0.938	0.733
Peru	1964	0.564	0.458
Saint Kitts and Nevis	−0.701	1990	−0.48
Saint Lucia	−0.793	9035	−0.113
Saint Vincent and the Grenadines	−0.181	1366	−0.407
Suriname	0.211	−0.001	−0.041
Trinidad and Tobago	0.076	−1407	0.338
Uruguay	1001	3881	0.16
Venezuela (Bolivarian Republic of)	0.625	−0.27	0.266
South America	1324	0.333	−0.253
Central America	0.846	0.146	−0.278
Caribbean	0.8	−0.001	1012
World	0.734	0.148	−0.015

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